RESPONSE-INITIATED IMAGING OF OPERANT BEHAVIOR USING A DIGITAL CAMERA

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A miniature digital camera, QuickCam® Pro 3000, intended for use with video e-mail, was modified so that snapshots were triggered by operant behavior emitted in a standard experimental chamber. With only minor modification, the manual shutter button on the camera was replaced with a simple switch closure via an I/O interface controlled by a PC computer. When the operant behavior activated the I/O switch, the camera took a snapshot of the subject's behavior at that moment. To illustrate the use of the camera, a simple experiment was designed to examine stereotypy and variability in topography of operant behavior under continuous reinforcement and extinction in 6 rats using food pellets as reinforcement. When a rat operated an omnidirectional pole suspended from the ceiling, it also took a picture of the topography of its own behavior at that moment. In a single session after shaping of pole movement (if necessary), blocks of continuous reinforcement, in which each response was reinforced, alternated with blocks of extinction (no reinforcement), with each block ending when 20 responses had occurred. The software supplied with the camera automatically stored each image and named image files successively within a session. The software that controlled the experiment also stored quantitative data regarding the operant behavior such as consecutive order, temporal location within the session, and response duration. This paper describes how the two data types—image information and numerical performance characteristics—can be combined for visual analysis. The experiment illustrates in images how response topography changes during shaping of pole movement, how response topography quickly becomes highly stereotyped during continuous reinforcement, and how response variability increases during extinction. The method of storing digital response-initiated snapshots should be useful for a variety of experimental situations that are intended to examine behavior change and topography.

Key words: response-initiated image taking, digital camera, frame-by-frame analysis, response topography, response variability, extinction, rats

One of the distinguishing features of an experimental analysis of behavior is the automated recording and control of behavior, which makes behavior analysis objective and places it within the realm of other natural sciences (Skinner, 1938). Especially with animal subjects, the experimenter can conduct long sessions and accumulate large amounts of data from a closed environment without disturbing the subject. Equipment used for experimental analysis often features a peephole or an attached videocamera for observation of behavior during sessions. Such observations are customarily done on an occasional basis to check equipment or to illustrate a behavioral phenomenon. Continued observation of a subject using observational techniques has not been commonplace in the

experimental analysis of behavior even though a considerable amount of information about behavior can be gathered that way to supplement the automated recording. Some examples of the use of observational techniques in operant conditioning are Laties, Weiss, Clark, and Reynolds (1965), who studied collateral behavior during schedules of differential reinforcement of low rate, and Henton and Iversen (1978), who examined the role of collateral behavior in a variety of experimental situations. Such visual observations of behavior not only supplement the automated recording but also provide ideas for new experiments (Iversen, 1991).

On occasion in the history of a science, someone has a very good idea that may later be forgotten because it was laborious to implement or because the theoretical issue that motivated the research no longer is popular. One outstanding example in experimental psychology is by Guthrie and Horton (1946), who designed an experiment in which the subject's behavior automatically triggered the shutter of a camera. Cats could escape from

a box by moving an omnidirectional pole that extended from the floor of the box. Each movement of the pole triggered the camera to store the topography of the behavior at that moment. The subsequent development, framing, labeling, sorting, and tracing of film and images must have been tremendously laborious. Guthrie and Horton used their method to examine the issue of response–reinforcer contiguity and demonstrated that the particular topography of rubbing against the pole, which was contiguous with the moment of reinforcement (opportunity to escape from the box), was highly likely to be repeated on subsequent trials. Moore and Stuttard (1979) later replicated part of this experiment with and without human observers present during sessions and noted that the cats rubbed against the pole when people were present but not when they were absent. Moore and Stuttard concluded that the cats were rubbing the pole to greet the experimenters and that the general principle of contiguity was not important because the pole response occurred whether reinforced or not. Moore and Stuttard, however, did not obtain response-initiated pictures and did not address the issues of response topography and response–reinforcement contiguity. Nonetheless, Moore and Stuttard's paper has resulted in a sort of discrediting of Guthrie and Horton's conclusions and hence in academic forgetting of their experiment and of the unique idea of storing response-initiated images of a subject's behavior. In the behavioral literature, images have on occasion been presented for a frame-by-frame analysis of performance that is otherwise difficult to visualize or describe (e.g., Davis & Hubbard, 1972; Epstein, 1985). Stroboscopic photography has been used on occasion to illustrate the minute details of the topography of pigeons' key pecking reinforced with food (Smith, 1974) or rats' lever pressing reinforced with shock escape (Rial, Saura, Todo, & Tur, 1987). A unique and well-known example of using response-produced images is the different forms of autoshaped key pecking in pigeons generated by food and water reinforcement (Jenkins & Moore, 1973). Apparently, the method of generating data albums of response-initiated images, as originally implemented by Guthrie and Horton, is used only rarely.

This article describes a relatively simple and inexpensive way to use modern computer equipment to reenact Guthrie and Horton's (1946) concept of conserving response-initiated images of a subject's behavior. A variety of inexpensive digital minicameras are now available that are intended for use with transmission of e-mail and other electronic messages. A bitmap image is created in a fraction of a second and the associated software automatically names each image. Hence, the image is developed, framed, labeled, and stored with no effort. By placing the camera near an experimental chamber, such a method could be used to capture moments of behavior. A problem with taking a snapshot of behavior using such a minicamera, however, is that to take a picture, the user has to observe the video image on a monitor and then place the mouse pointer over an icon some other place on the monitor and then press a mouse button. Such a method could be useful but would nonetheless miss the gist of Guthrie and Horton's idea of an automated system that takes the picture the moment the behavior of interest occurs. In essence, the method has to enable an experimental subject to take a picture of itself.

A search of available digital minicamera products revealed that a few such cameras are outfitted with a manual snapshot button. By taking the camera apart, one can disconnect the shutter button and replace it with a computer-controlled switch. With this method a snapshot of specific behavior can be taken the moment that behavior occurs, just as a food pellet can be delivered the moment the behavior occurs. This article describes how one can modify and connect a QuickCam® Pro 3000 (Logitech, Inc.) digital camera to experimental equipment. The camera including software is relatively inexpensive ($99, August 2001), and the modification requires only minimal knowledge of wiring and switch operation. The use of the QuickCam® is illustrated in a simple experiment using rats as subjects and an omnidirectional pole that extended from the ceiling of the chamber as the response manipulandum. Each movement of the pole activated the shutter on the QuickCam®. In addition, by triggering the snapshot with the button press that the experimenter used to shape the behavior, the

setup could also store a succession of images from shaping of pole movement.

Variability in different dimensions of operant behavior, such as response duration and response force, is known to narrow under continuous reinforcement (CRF) and to widen under extinction (Antonitis, 1951; Neuringer, Kornell, & Olufs, 2001; Notterman & Mintz, 1965). The present experiment sought to determine whether the same rule also holds for topography of operant behavior under CRF and extinction. Because acquisition and extinction of operant behavior can be demonstrated reliably in individual subjects within a single session (e.g., Skinner, 1938) the present experiment alternated blocks CRF, in which each response instance was reinforced, with blocks of extinction, in which the response was not reinforced, in one session in which each block ended when 20 responses had occurred. To enable an analysis of response topography, each response produced a digital image of how the rat made that response.

METHOD

Subjects

Six female Sprague Dawley albino rats, approximately 9 months old, were used in the experiment. All rats had prior experience in operant chambers with food pellets as reinforcement. Rats M1, M2, M3, and M4 had participated in an experiment on delayed reinforcement with lever pressing as the response. Rats C2 and C3 had participated in an experiment on stimulus–response chains using both lever pressing and pushing an omnidirectional pole as the responses. The rats were maintained at 85% of their free-feeding body weights and weighed 260 to 310 g prior to weight reduction. Water was available in the home cages, and the colony was maintained on a 12:12 hr light/dark cycle.

Apparatus

Operant equipment. A MedAssociates, Inc., modular test chamber (ENV 008-VP) was equipped with a 45-mg pellet feeder (ENV-203). Pellet delivery was accompanied by a 200 ms "beep" from a Sonalert (Model SCG28). The box was 30 cm wide, 24 cm deep, and 21 cm high. One wall had a centrally located feeder opening and two levers.

The feeder opening was 1.5 cm above the floor, 5.5 cm wide, 5 cm high, and 3 cm deep. The levers were positioned 7 cm above the floor and 3 cm from the edge of the feeder opening; the levers were 4.7 cm wide and protruded 1.8 cm into the chamber. The levers were not used in the experiment. An omnidirectional pole, 12 cm long and 0.5 cm wide, was suspended from the center of the ceiling. Movement of the tip of the pole of at least 0.5 cm in any direction with a force of at least 0.15 N constituted a measured response. Entry to the feeder area was measured as the head of the rat broke a beam of infrared light. An infrared light-emitting diode (LED; Radioshack® 276-143C) was positioned outside a small hole in the side of the feeder tray, 1 cm above the bottom of the tray and 1 cm from the wall with the levers. A photo transistor (Radioshack® 276-145A) was located outside a small hole on the opposing side of the feeder tray. The photo transistor was connected to a PhotoMos relay (NAIS AQZ102) for input to the computer. A 6-W cool white neon overhead light (21 cm wide and mounted 2.5 cm above the cage) provided sufficient light for image taking. A PC computer (NEC 425) controlled the experiment using a program written in QuickBASIC by the experimenter. Response inputs and control outputs were accomplished without an interface card using only the PC's parallel printer port (see the Appendix).

Camera. A QuickCam® Pro 3000, which features a manual shutter button in addition to software control of the shutter, was disassembled and modified slightly. The camera has manual focus and a shutter speed of 1/30 s. Frame A in Figure 1 shows the camera before disassembly (for its intended use, the camera ordinarily rests on a pod). The manual shutter button is located at the top of the shell. The shell can be opened after removal of a single screw. Frame B shows the shell and the contents after opening. The shutter button is easily identified (top middle) and has two sets of wires attached to it. One double wire (white) is for a built-in microphone that was not used in the present experiment. Two additional wires (brown and black) connect the shutter button to the camera. These wires were cut to isolate the camera (Frame C). Once isolated from the shell and shutter button, the camera occupies less than 5 cm in
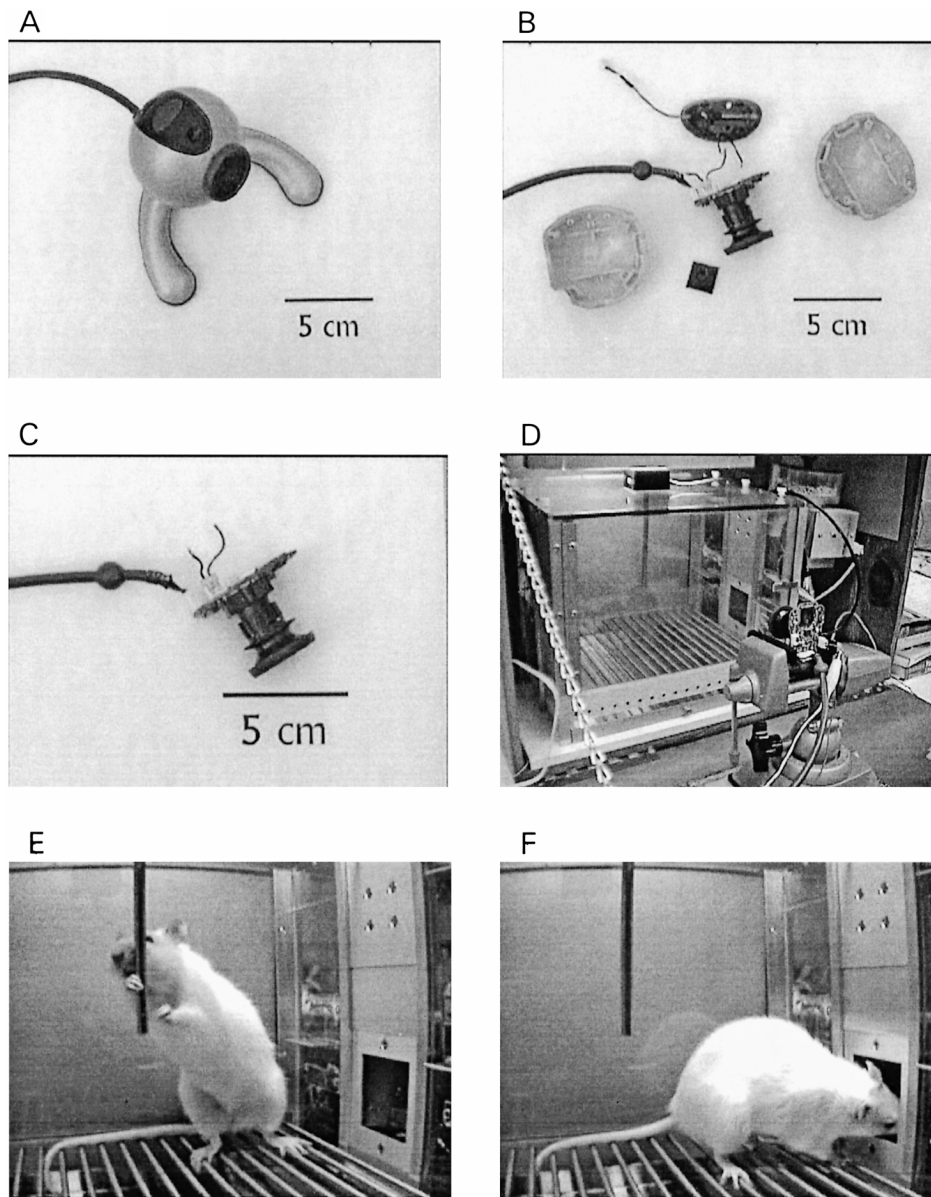
Fig. 1. Photographs of the QuickCam® Pro 3000 before (A) and after (B) disassembly. The camera is isolated from the manual shutter button (C), and the two wires that ordinarily connect the camera to the shutter button can instead be connected to an alternative switch so that the camera can be operated remotely. For this experiment, the camera was located outside the experimental chamber (D). The camera was wired so that it was triggered by an operant response. The result is that the rat takes a picture of itself (E). The camera can also be operated by the experimenter via the software so as to take pictures of other performances (F).

all directions and has only one cable, which connects it to the USB port of a PC computer. The QuickCam® was mounted on a small portable vise and placed outside the chamber (Frame D), 15 cm from the door of the chamber for Rats M1, M2, M3, and M4 and 10 cm from the door for Rats C2 and C3. A small LED attached to the camera is lit when the camera is connected to the PC. This LED was covered to avoid its reflection in the equipment.

The minimum hardware requirements for

use of the camera and software are a 300-MHz Pentium® II computer, a USB port, and Windows® 98 or later. The computer used for image processing in this experiment was a Hewlett Packard Pavilion 4550z with an Intel® Celeron™ 466-MHz processor. The image size used in this experiment was 160 × 120 pixels with a processing time after capture estimated to be about 0.5 s. The QuickCam® and its software can also process image sizes of 320 × 240 and 640 × 480 pixels, but with the PC computer used in the present experiment the processing time for each image was increased considerably compared with that for the 160 × 120 size. The QuickCam® software features a window on the left side of the monitor that shows the image seen by the camera, which can be used for on-line monitoring. The snapshot images taken by the camera are shown as thumbnails in a window on the right side of the monitor. The software automatically names the snapshots successively as Picture 1, Picture 2, and so on. After a session the images can be saved in a folder with a name appropriate for the session. The software generates a "click" sound from the computer's speaker each time the shutter is operated; this sound was useful for testing but was disabled during actual use. Thus, the experimental subject can take a picture via the external switch, and the experimenter can take a picture via the software "switch" that is enabled by a mouse click. Frame E in Figure 1 shows an example of an image triggered by the subject's behavior. Frame F shows an example of an experimenter-generated image of the rat picking up the food from the feeder. With the system used for the present experiment, several hundred images were taken in a single session, which posed no problems for the software, memory storage, or image display features.

The logic of the use of the camera for experimental purposes was to modify it so that the experimental subject can operate the shutter button, thereby enabling response-initiated snapshot imaging. To make the response operandum act as the shutter button, the two wires that connected the camera to the original manual shutter button were instead connected to the common (C) and normally open (NO) pins of a simple switch. This switch could be that which is ordinarily attached directly to the response operandum. Customarily, however, the switch on the re-

sponse operandum is already connected to control equipment. In addition, there may be a need for selective software control of when an image can be taken. Therefore, the wires from the camera were connected to the C and NO pins of an opticoupler relay (PhotoMos®, NAIS AQZ102) that was operated from the parallel printer port of the PC computer that controlled the experiment (see the Appendix).

Software. Additional software used, which was not supplied with the camera, was Image Expert 2000 (Sierra Imaging, Version 3.2.1, $45.00, August 2001). This software can easily open an album with several hundred images and sort them in consecutive order. Thus, all images from a session are available for simultaneous viewing or can be seen with minimal scrolling (a full screen shows 70 images with the file name of each image shown above the image). Without being modified, the images that were used for illustration here were transferred one by one from Image Expert 2000 directly onto a word-processing page (e.g., WORD97 Microsoft®) with a simple click-and-drag method when two windows, one for Image Expert and one for WORD, were opened simultaneously on the monitor. Using this image software, mounting the images took just a few minutes for each of the figures presented here. The word-processing software was then used to supply additional text information.

Although the file properties for each image include the time the image was taken, this information is cumbersome to obtain when several hundred images are taken. Therefore, the software that controlled the experiment was arranged to save information about each response instance made (e.g., its successive number within the session, its duration, its time of occurrence since session start, and whether it was reinforced or not). This information was then analyzed later in conjunction with the individual images; these were also numbered successively for each session by the camera software. Thus, each image was directly linked with numerical information about the response that produced that image.

Procedure

Each rat had prior experience in the equipment used, so magazine training was not necessary. Rats M1, M2, M3, and M4 had no experience with the pole, whereas the pole had

been part of a stimulus–response chain for Rats C2 and C3. Rats M1 and C2 touched the pole shortly after entering the chamber, and shaping was not necessary. Rats M2, M3, M4, and C3 did not move the pole within the first 10 min of the session, and manual shaping of pole movement was used to make the response occur (e.g., Gleeson, 1991). Shaping was accomplished in a few minutes using from 8 to 15 reinforcers for each rat. Once a rat made an automatically recorded pole response, the shaping procedure was terminated and the response was then reinforced under CRF for up to 20 reinforcers (including those used in shaping). Each rat had an alternation of blocks of CRF, in which each of 20 responses was reinforced, with blocks of extinction, in which each of 20 responses was unreinforced. The first block in the session (after shaping, if necessary) was CRF. The single session comprising the experiment was terminated after five or six blocks of CRF.

The experiment tested the use of the camera to examine response topography under CRF and extinction; hence the repeated within-session alternation of blocks of CRF and extinction. The onset of the pole response produced the food pellet and triggered the shutter on the camera. The full duration of each pole response (from onset to offset of the automatically recorded pole movement) was stored under both CRF and extinction (except for Rat M1, which served first as the "test" rat; recording of food-tray entry and response duration was implemented after Rat M1 was tested because observations of this rat's performance suggested that such measures would provide useful supplemental information).

RESULTS

The main purpose of the experiment was to illustrate the use of the camera. Hence, this brief experiment was not intended to constitute a thorough experimental analysis of response stereotypy and response variability under CRF and extinction. Nonetheless, some quantitative data are given because the within- and across-subject replication design generated reliable data.

Shaping

Figure 2 shows the use of the camera to illustrate change in response topography during the process of shaping a novel response. Rat M2 did not engage the pole for 10 min prior to shaping other than occasionally sniffing at it. The experimenter then initiated shaping manually by pressing a switch that operated the feeder as well as the camera. A pole response made by the rat also operated both the feeder and the camera. Each reinforcer is numbered along with its time of occurrence within the session (seconds since start of shaping). The experimenter provided reinforcement first for being near the pole (Frame 1), then for sniffing the pole (Frames 2 through 8), then for touching the pole (Frames 9 and 10), and then for moving the pole slightly (Frames 11 and 12). The first pole response detected by the recording device is seen in Frame 13 (after 6 min and 5 s); the experimenter stopped manual reinforcement at that point, and the pole response produced the next seven reinforcers. Notice how the topography of pole movement quickly became stereotyped when the rat operated the feeder directly, as seen in the nearly identical posture of the rat in the last six frames (15 through 20). Although the images are only postage-stamp size, they nonetheless show sufficient detail to illustrate the topography change that takes place in an ordinary 5- to 10-min shaping session.

Continuous Reinforcement

To illustrate that the topography of the pole response quickly became stereotyped for each rat under CRF, Figure 3 shows the last five pole responses in the first block of CRF for each rat (the camera was placed closer to the chamber for Rats C2 and C3, hence the more detailed images). The response topography differed across rats, yet, for each rat, the successive frames show a remarkable similarity in topography of pole movement. Notice, for example, the paw grip on the pole for Rats C2 and C3, which is nearly identical from frame to frame. For all rats, the topography of pole movement was not only highly stereotyped within each block of CRF but also across blocks, as illustrated in Figure 4, which shows the last five responses from each block of CRF for 1 rat. The images look nearly identical. Yet, a slight, systematic change in response topography emerged gradually within the session from touching the upper part of the pole with both paws in the beginning of
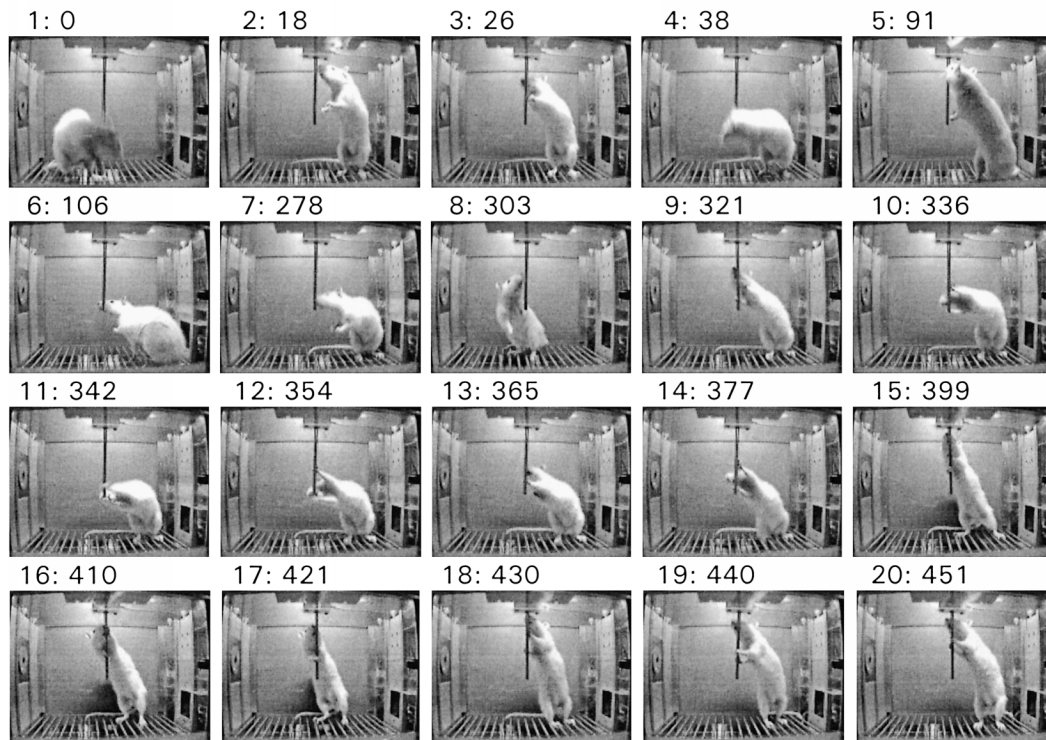
Rat M2

Shaping: Frames1-13, CRF: 14-20

Fig. 2. Images from shaping of pole movement for 1 rat. The experimenter held a switch that activated both the feeder and the camera shutter. The camera shutter was also activated by onset of the pole response. Shaping was accomplished when the rat made a pole response in Frame 13; each pole movement was then reinforced under CRF for an additional seven reinforcers.

the session to touching the lower part of the pole with the right paw toward the end of the session. The force requirement to activate the pole was 0.15 N at the bottom of the pole but was 0.25 N at the middle of the pole. Conceivably this force difference was a contributing factor in the gradual selection of pole movement at the lower end of the pole, which was noted for all rats. In spite of this relatively minor change in topography, Figure 4 illustrates the more general picture of rapid development within one session of a highly stereotyped performance when pole movement is reinforced.

Extinction

The topography of pole movement changed during extinction, as illustrated for 1 rat in Figure 5. The figure shows all 20 responses in the fourth block of extinction, and, for comparison, the last five responses of the preceding block of CRF and the first five responses of the following block of CRF. The pole response was highly stereotyped under CRF, as seen in the top and bottom frames in Figure 5. The first two pole responses in extinction are quite similar in topography to the reinforced responses in the prior block of CRF, but the third and fifth extinction responses differ in topography. After 10 responses the rat engaged the pole from different directions. Novel topographies emerged under extinction, such as moving the pole from the left side of the chamber (Frames 152 and 155) or engaging the pole with both paws (Frames 156 and 157). As soon as the pole response produced reinforcer delivery again in the next block of CRF,

Last 5 Responses in First Block of CRF
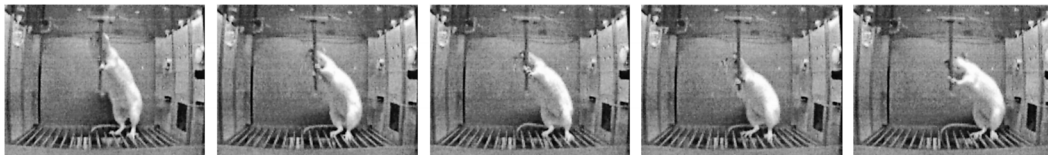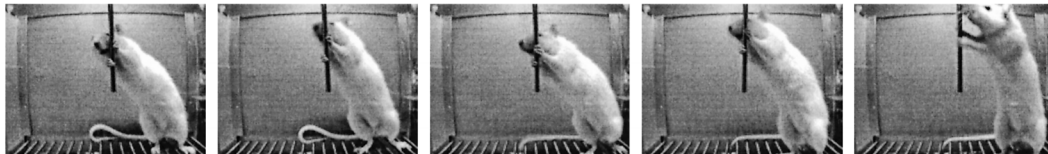
Rat: M1
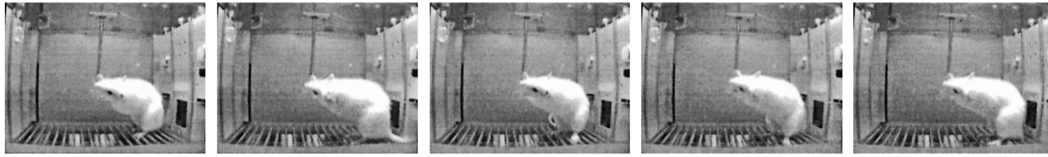
M2

M3

M4

C2

C3

Fig. 3.   Images of response topography at the onset of pole movement for the last five responses of the first block of CRF (following shaping, if necessary) for each rat.

the topography immediately switched back to that seen previously in the first block of CRF, and then almost no variation occurred from frame to frame. All rats showed similar increased variation in extinction with emergence of response forms not seen under CRF or earlier under shaping. Also, following a block of extinction, all rats immediately returned to the previously reinforced response

topography after the first or second reinforced response.

Response Duration and Response Topography

When the performance was highly stereotyped under CRF, the duration of the pole response was very short. But, under extinction, the response duration varied consider-
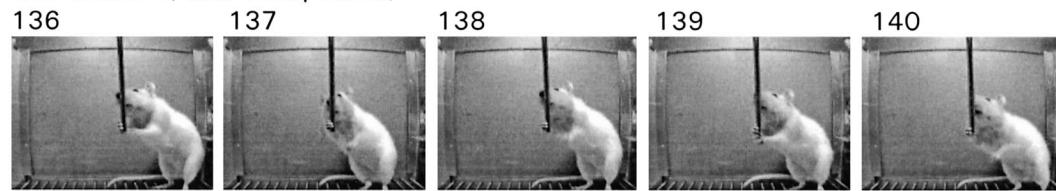
Rat C3

Last 5 responses in Each Block of CRF

Fig. 4. Images of response topography at the onset of pole movement for the last five responses of each block of CRF for 1 rat.

ably. Table 1 shows the average duration of the pole response under CRF and extinction (along with standard deviations and absolute ranges) for Rats M2, M3, M4, C2, and C3 (duration data were not available for Rat M1). Across rats, the average response duration was between 0.17 s and 0.23 s under CRF,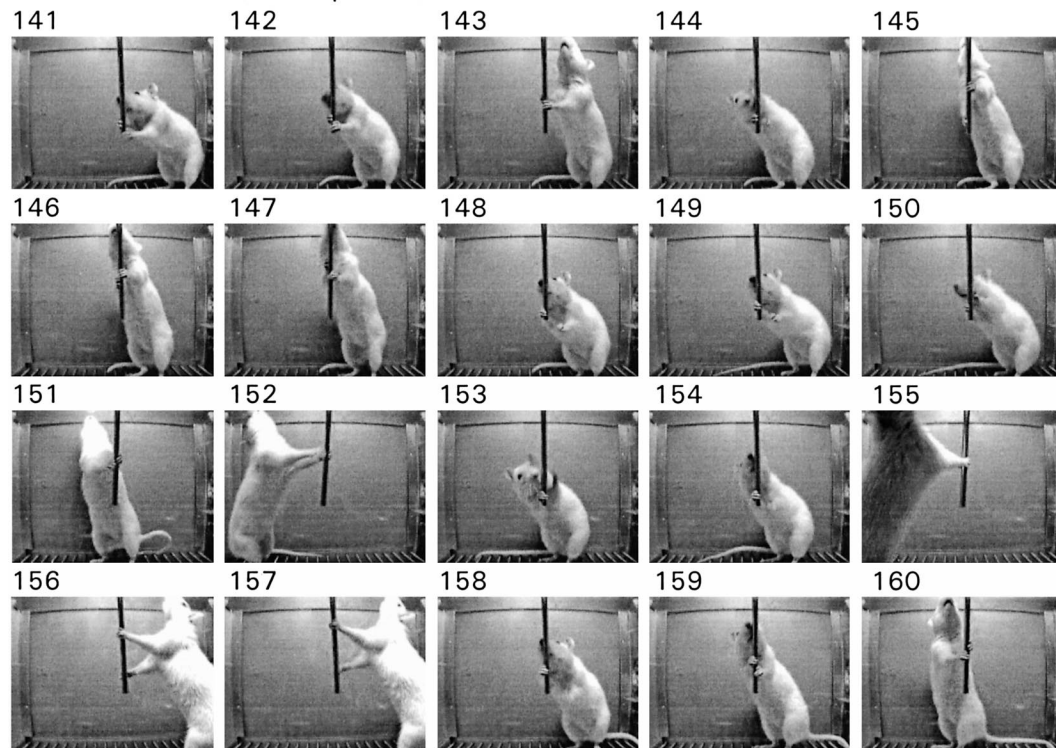 with an absolute range of 0.14 to 1.4 s. Prob-ably because of their prior experience with pole movement, Rats C2 and C3 had the smallest standard deviations and the smallest absolute range under CRF. Under extinction, average response durations more than doubled for each rat, along with a considerable increase in the standard deviations (especially for Rats C2 and C3). The increased variability

Rat M4

CRF (Block 4, last 5 responses)

| 136 | 137 | 138 | 139 | 140 |

Extinction (Block 4, all responses)

| 141 | 142 | 143 | 144 | 145 |

| 146 | 147 | 148 | 149 | 150 |

| 151 | 152 | 153 | 154 | 155 |

| 156 | 157 | 158 | 159 | 160 |

CRF (Block 5, first 5 responses)
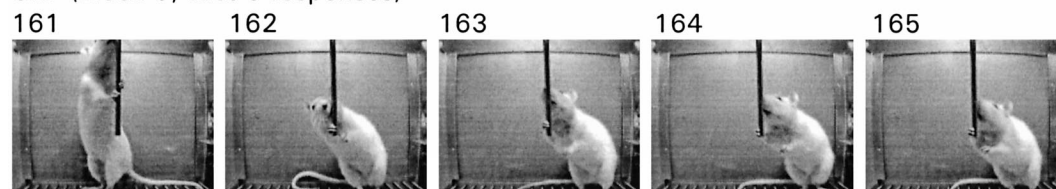
| 161 | 162 | 163 | 164 | 165 |

Fig. 5.   Top: images of response topography during pole movement for the last five responses during the fourth block of CRF. Middle: images of each pole response during the fourth block of extinction. Bottom: images of the first five pole responses during the fifth block of CRF. Frames are numbered successively within the session.

Table 1

Average duration of pole movement for each rat under CRF and extinction. Each rat had one session with blocks of 20 reinforced responses alternating with blocks of 20 unreinforced responses. Data are shown as the average, in seconds, with standard deviation (*SD*) and absolute ranges in parentheses. Response-duration data were not available for Rat M1.

Rat	CRF	Extinction
M2	0.22 (0.12, 0.14–1.16)	0.48 (0.74, 0.14–8.86)
M3	0.21 (0.20, 0.14–1.43)	0.44 (0.72, 0.15–2.36)
M4	0.23 (0.15, 0.15–1.20)	0.61 (0.75, 0.15–3.02)
C2	0.17 (0.05, 0.14–0.31)	0.44 (0.88, 0.15–5.54)
C3	0.17 (0.04, 0.15–0.47)	0.79 (1.53, 0.15–7.18)

is evident in the large increase in the upper bound of the absolute range; some individual responses lasted more than 8 s. The average data in Table 1 combined with the image information seem to suggest an overall correlation between topography and response duration such that short response durations under CRF occurred along with a highly stereotyped response topography and long response durations under extinction occurred along with a variable topography. A more detailed examination of the images in conjunction with the duration data suggests, however, that novel topographies seen under extinction are not necessarily linked with longer response durations. Figure 6 demonstrates for 1 rat how topography and response duration can be compared visually by sorting images conditionally on the other dimension of response duration. Thus, the left column shows images produced by a response with a duration in the 0- to 0.19-s range, the second column shows images when the response duration was between 0.2 s and 0.49 s, and so on. The total number of responses (*N*) is shown for each bin. Data are from the first three blocks of extinction. If sufficient space were available to show more images, this data display could form a complete histogram with each image being one data entry. Only for the bins for 1.0 to 2.99 s and for 3 s and above do the frames show all the data. For the other bins, the experimenter chose images representative of the topography variation seen within that bin of response duration. Numbers above a frame indicate the sequential response order within the session and also serve to identify the frame. As previously shown in Figure 4, the topography of pole movement

was highly stereotyped under CRF for Rat C3, and practically all response durations were shorter than 0.2 s (Table 1). Under extinction, the topography varied, as did the response durations. The variation in response topography, however, was not related to the variation in response duration. For example, Images 80, 75, 105, and 119 in Figure 6 in the 0.5- to 2.99-s range show a topography similar to that seen under CRF (cf. Figure 4), yet the response duration far exceeded that under CRF. Some of the novel topographies seen in extinction, such as Frames 36, 67, 72, 111, and 108, are associated with response durations as short as those obtained under CRF. This method of sorting images conditional upon the response duration was implemented for the remaining rats as well. All rats showed the same overall pattern of results, suggesting more generally that under extinction the increased variabilities in response duration and in response topography are independent. Thus, a novel response topography apparently does not result from a novel response duration and vice versa.

Multidimensional Data Displays

Response-initiated snapshot images can be integrated with numerical information to give an impression of the temporal aspects of the overall performance. To illustrate one such possibility, Figure 7 shows the temporal location and duration of each pole response for Rat C3 for the third block of CRF and for the following block of extinction. Snapshot images are shown intermittently to indicate what the performance looked like. In addition, the display shows when entry to the food tray occurred and for how long. Pole movement is indicated by the bars above the line; tray entry is shown by bars below the line. For both response types, the duration of a given instance is indicated by the width of the bar. An image corresponds to the pole response under the left edge of the image.

Under CRF the pole response was spaced regularly, with interresponse times of a little over 10 s. The images show that the pole response occurred in the same form for nearly all responses (except the first). All pole responses were very brief, usually less than 0.2 s (Table 1). Entry into the food tray quickly followed each reinforced pole response and lasted a few seconds. Under CRF, tray entry

Rat C3
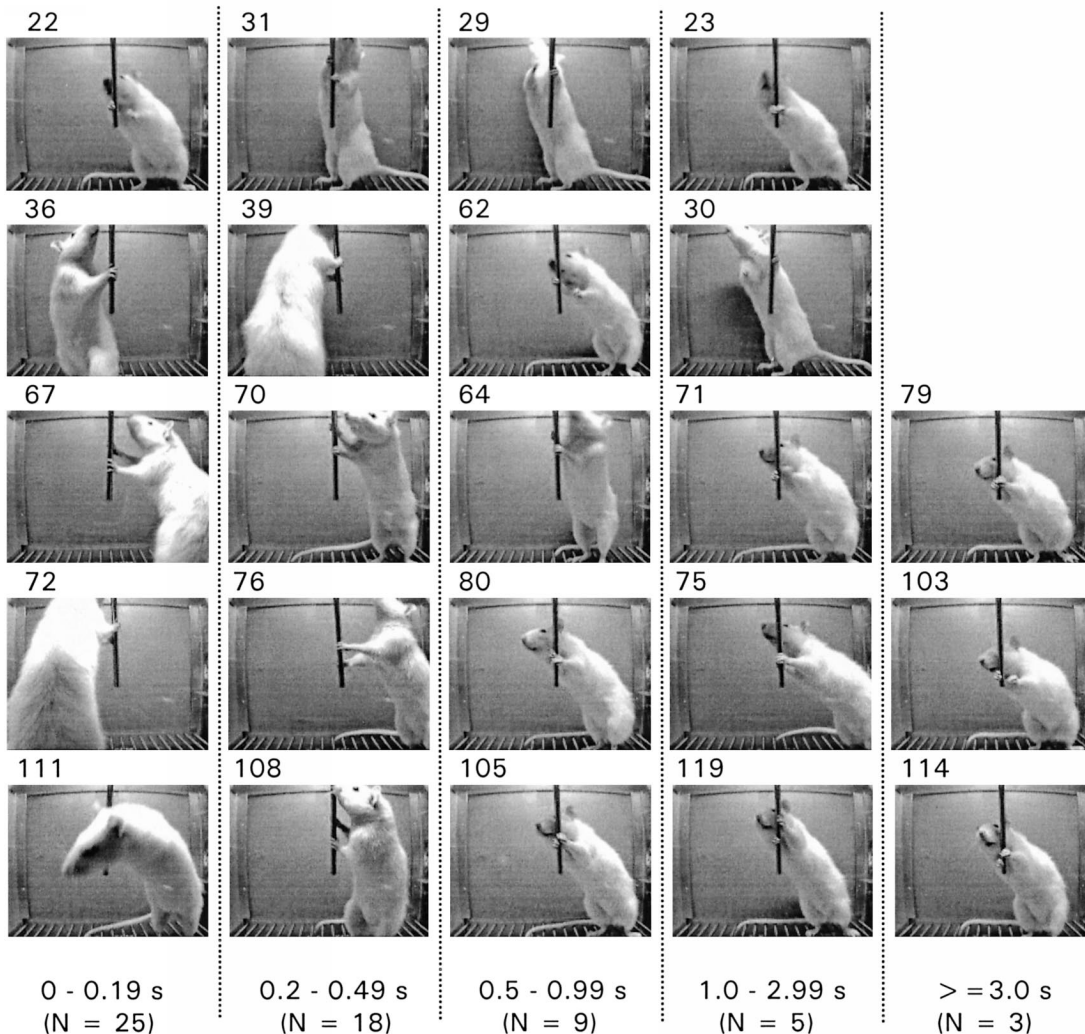
Pole Response Duration

Fig. 6. Sorting of images of response topography under extinction conditional upon the duration of the pole response. Images in a column correspond to onset of pole responses with a duration within the bin indicated under the column. Because more responses occurred in the shorter bins than can be shown on one page, representative images were chosen by the experimenter for the first three bins; images in the last two bins show the topography of all responses obtained in those bins. Frame numbers refer to successive response locations within the session. Data are from the first three blocks of extinction for 1 rat.

also occurred in one or two brief bouts a few seconds before each pole response.

Under extinction, the pole response occurred with short interresponse times and at longer durations during the first 30 s; for example, the third pole response was over 5 s long. Then responses occurred with longer interresponse times and at irregular durations for the remainder of the extinction period. The images show that under extinction the response topography was the same as under CRF for some responses and differed considerably for other responses. A longer response duration, however, did not necessarily
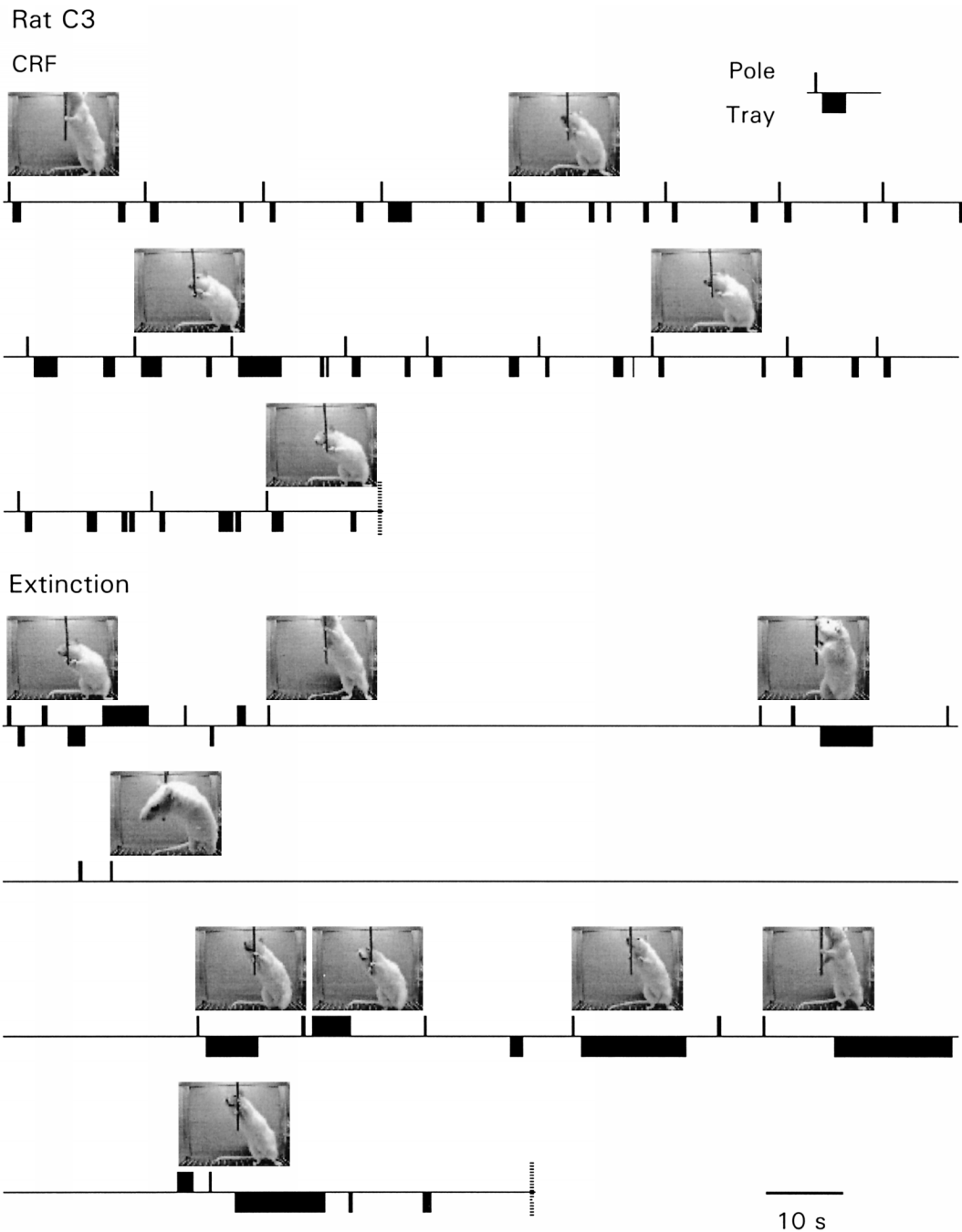
Fig. 7. Illustration of a real-time display of temporal pole-response location, pole-response duration, tray-entry temporal location, tray-entry duration, and images of pole-response topography. Data are shown for 1 rat for the second block of CRF and the following block of extinction. Time passes from left to right. The pole response is shown as a bar pointing up, and entry into the food tray is shown as a bar pointing down; for both responses bar width indicates response duration. Images relate to the response that occurs at the left edge of the image. For ease of presentation, the record is broken when the first CRF ended, as indicated by vertical hatching (the first response in extinction occurred at that moment and is shown instead on a new line). The CRF block lasted 5 min and 4 s, and the extinction block lasted 7 min and 32 s. Images used in this figure were reduced to 46% of their original size.

occur along with a topography change, as shown for the first two images in the third line for extinction. Tray entry followed some pole responses but not as quickly as when the pole response was reinforced under CRF. The bouts of tray entry under extinction often exceeded 10 s. Also, under extinction a brief tray entry did not precede the pole response as it did under CRF.

This simultaneous display of temporal location and duration of two different responses as well as the occasional indication of response topography in snapshot images under two different experimental conditions, CRF and extinction, shows how all the essential performance characteristics can come together in one view.

DISCUSSION

The present experiment served to illustrate how the method of capturing response-initiated images of operant behavior can address important issues such as stereotypy and variability in response topography under acquisition, extinction, and reacquisition of operant behavior. The response stereotypy, which developed quickly under CRF within a single session, was striking in its uniformity from image to image and from block to block for each rat. Equally striking was the variability in pole movement topography seen for each rat within each block of extinction. A single session can be sufficient to demonstrate important characteristics of acquisition and extinction of operant behavior because, as in the present experiment and many before it (e.g., Skinner, 1938), the data were highly consistent across subjects. As such, the present demonstration of response-topography changes during shaping, acquisition, extinction, and reacquisition of operant behavior could serve as an educational vehicle, for example for undergraduate students, to illustrate basic behavioral principles.

The images suggested that many of the novel topographies of pole movement that emerged under extinction had not occurred previously under shaping and continuous reinforcement. This preliminary finding is compatible with previous examinations of response-duration and response-force changes during extinction (Notterman & Mintz, 1965). The emergence of such novel and pre-

viously unreinforced response topographies is important theoretically for an understanding of response class formation and how the process of shaping works. The combination of pictorial information with other measures of behavior used in the present experiment, such as the duration of each response, showed that the variability in response topography and the variability in response duration in extinction were not linked moment to moment. Of particular interest was the finding that the topography variation began after just two or three unreinforced responses. Response duration increased as soon as a response was not reinforced because the stimulus that ordinarily stops the response, the sound of food delivery, was lacking. The images were taken at response onset, and the data, therefore, showed that variation in response topography seen in extinction did not come about because the rat was holding the pole for a longer duration. Rather, visual observations indicated that one source of the varying topography in extinction was that the rat approached the pole from different directions. Under CRF the rat primarily approached the pole from the feeder area and almost always in the same manner. A more thorough experimental investigation of these issues using image information would require methods for quantification of response topography based on interrater reliability assessments (e.g., Cooper, Heron, & Heward, 1987) or automated image analyses (e.g., Rousseau, Van Lochem, Gispen, & Spruijt, 2000). Image information also serves as an important impetus for development of automated, direct recording of movement. For example, early photographic illustrations of pigeons' key pecking (Jenkins & Moore, 1973) motivated subsequent development of automated monitoring techniques that provide impressive, high-resolution data on the kinematics of pigeons' head and jaw movements during ingestive and conditioned pecking (Bermejo & Zeigler, 1998).

The digital QuickCam® was easy to modify so that the response made by the experimental subject triggered the shutter. Any computer interface system that allows control over a simple switch closure can be used to trigger the camera. The use of the parallel printer port in the application used here worked flawlessly. The digital images stored by the

computer could be mounted easily for presentation in figures using common word-processing software. Guthrie and Horton (1946) used the method of capturing response-initiated images of a subject's behavior to analyze the role of contiguity between response and reinforcement, but the method has not been used routinely since then. The results of the present experiment suggest that modern digital camera equipment can be used to establish a method for obtaining pictorial information about behavior that is not ordinarily obtained. To arrange for a subject to take a picture of its own behavior has great potential as an analytic tool in a variety of experimental situations and can be used for any species of subject.

The camera method could be expanded further by selecting certain responses for storage such as, for example, the first, middle, and last responses on a fixed-ratio schedule of reinforcement. Experimental events such as reinforcement delivery in response-independent food-delivery schedules could also be arranged to trigger images to cast a light on what the subject is doing at the moment of reinforcement. For example, to analyze the effects of adventitious reinforcement, a control program can be set to take a snapshot of the subject's behavior when the reinforcer is delivered and additional snapshots each second thereafter for, say, up to 30 s. In this manner one can obtain a pictorial record of performance changes that documents the effects of a single reinforcement (cf. Henton & Iversen, 1978, chap. 4). By taking an image at the moment of reinforcer delivery during the process of shaping, one can document how shaping takes place as well as examine how different experimenters shape behavior. Specifically, such a method can be used to examine which shaping strategies are effective and which are ineffective and can therefore be used to give trainers feedback about how well they did. Similarly, other experimental events, such as the onset of a discriminative stimulus in an operant conditioning paradigm or a conditioned stimulus in a Pavlovian conditioning paradigm, can be used to trigger a snapshot of what the subject is doing at that moment. Such images can provide data that aid an understanding of the effects of sequential dependencies in behavior. For example, the topography of the behavior that occurs at the onset of a discriminative stimulus can be used to predict the length of the reaction time between onset of the stimulus and the operant response that the stimulus controls (Henton & Iversen, 1978, chap. 5; see also Henton, 1981, for a similar effect in classical conditioning).

The camera method can also be used to examine what takes place during voids in operant behavior generated in experimental procedures such as differential-reinforcement-of-low-rate schedules or signaled or unsignaled delayed reinforcement. For example, with a 10-s delayed reinforcement procedure, the camera could be programmed to take an image each second during the delay. Such information can be used to determine the extent to which responses other than the measured operant participate in the acquisition of operant behavior with delayed reinforcement. Specifically, the method can be used to determine whether the subject lingers near the operandum at the time of reinforcement; such behavior could be accidentally reinforced and might thereby increase in frequency, resulting in an increased probability that the subject would also emit the operant response. Similarly, with time-driven shutter control, the camera can capture what happens second by second during a conditioned stimulus in a classical conditioning or autoshaping procedure.

In addition to serving the purpose of generating pictorial data for an experimental analysis, an album of images can also be used for pedagogic purposes. For example, the finding of response stereotypy under reinforcement and response variability under extinction would be particularly easy to communicate to an audience unfamiliar with behavioral principles by showing a transparency with images such as those presented here in Figures 3, 4, and 5. Also, the process of shaping can be illustrated in images when the camera is triggered by reinforcer delivery, as shown in Figure 2.

One feature of pole movement that was not captured by the snapshot method used here was that the rats on occasion moved the pole back and forth in a rapid rocking motion resulting in emission of two to five responses within a period of less than 1 s. With the QuickCam equipment and computer used in the present demonstration, the processing

time of each image was estimated to be about 0.5 s. An interimage interval of 1 s was added to the shutter-control software to ensure that images and responses corresponded perfectly (see the Appendix). Hence, occasional bursts of a few rapid pole responses were not captured by the camera if the interresponse interval was less than 1 s. In such cases, however, the loss of information is not considerable, because the rats maintained the same overall posture during a burst. Presumably, with a faster computer the processing time can be reduced so that the minimum interresponse time can be shortened further.

A possible limitation of the response-initiated snapshot method is that certain kinds of visual information about behavior may not be captured. For example, response topographies that engage the pole but do not move the pole sufficiently to activate the response sensor, such as gently rocking the pole while sniffing at it, will not activate the shutter. Hence, image information about such response changes cannot be obtained. One may note, however, that far more visual information is lost by not using any imaging or observational method. One possible inconvenience noted with the QuickCam® software was that when an album of images was loaded back into the software for later examination, the images did not appear in successive order even when sorted by date. When loaded into Image Expert 2000, however, album images did appear in successive order when sorted by date. Selecting the images and mounting them on a page using common word-processing software with a standard click-and-drag method proved to be particularly easy without any modification of the images. When images were reduced in size for a particular application (e.g., Figure 7), each image had to be reduced separately (either the Image Expert 2000 or a common Paint program can be used for that purpose).

Although there is nothing new about taking a picture of a subject's behavior during an experiment, the present method offers a novel and rather simple way to automate the process of taking pictures and storing them. The response-initiated triggering of the image is a method superior to that of an experimenter pressing a button the moment the response occurs, because the automated method eliminates the latency associated with the experimenter pressing a button after the behavior occurs. Similarly, although a video stream can be "frozen" to generate still pictures for analysis, the process of doing so is not particularly fast, and the moment a given response starts may be difficult to determine accurately. With response-initiated images, the event that triggers image taking is defined objectively and precisely. The images generated are, of course, still subject to interpretation by the experimenter, as are any other data collected from experiments. Yet, photographic images have a certain authentic appeal because they can be presented or published as raw or illustrative data so that other researchers can directly evaluate the information they provide.

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APPENDIX

Use of the Parallel Printer Port for Experimental Control

Because use of the printer port for experimental control may not be common, a brief description is given here (see also Cushman, 1993; Dalrymple-Alford, 1992). Gollub (1991) provides additional information about connecting experimental equipment to computers. The printer port ordinarily sends information to and receives information from the printer attached to a computer. Therefore, this port can be used as an interface for experimental control that is simple, inexpensive, and does not require an external power supply. The printer port can support eight outputs to and five inputs from experimental equipment.

Output. On the PC's printer port socket, Pins 2 through 9 represent outputs from the computer, with Pin 2 corresponding to Data Bit 0. Each of these pins rests at +5 VDC relative to ground (which is found at Pins 18 through 25). Pins 2 through 9 are asserted by writing the data byte to Port 888. An asserted pin shifts from +5 VDC to ground. For example, using QuickBASIC as the software control language, to assert Pin 2 (Data Bit 0), the code is ''OUT(888), 1'' (i.e., $2^0 = 1$; with the exponent of 2 being the data bit), and to switch it back is ''OUT(888), 0''; for Pin 3 (Data Bit 1) the line is ''OUT(888), 2'' (i.e., $2^1 = 2$), and so on. To convert this signal to simple switch closure, an opticoupler relay (PhotoMos®, NAIS AQZ102) was attached to each output pin on the printer port. The opticoupler relay isolates the PC's printer port from the experimental equipment. Each opticoupler relay has four pins, two to operate it (ground and +5 VDC) and two for the switch that operates external equipment (common, C, and normally open, NO). Thus, the two wires that ordinarily connect the QuickCam to its manual shutter were cut and instead connected to the C and NO pins of an opticoupler relay, which in turn was operated via one of the output pins of the PC's parallel printer port. In essence, the switch in the opticoupler relay replaced the shutter button on the QuickCam®. The pellet feeder was operated by another opticoupler relay that was connected to another output pin of the printer port.

Input. Pins 10, 11, 12, 13, and 15 on the printer port are inputs to the PC. Pin input can be read from Port 889. These inputs work as simple switch closures, and one could in principle attach the C from a response switch directly to the PC's ground (Pins 18 through 25) and the NO from the switch to one of the input pins. To protect the PC from accidental shorting of pins on the printer port, however, one can attach opticoupler relays between the external switch and the parallel port pins. Using QuickBASIC, for example, to read an input from Pin 15, the code is ''RespX = INP(889).'' The variable, RespX, has a resting value when no inputs are presented; this value apparently varies with the computer used. If an input is presented at Pin 15, the value of RespX drops by −8; for an input on Pin 13 the value drops by −16, for Pin 12 it drops by −32, for Pin 10 it drops by −64, but for Pin 11 it increases by +128.

The following code written in QuickBASIC shows how one can read from and write to the printer port so that an input on Pin 15 generates an output on Pin 2 that lasts about

0.056 s (the PC's internal timer is accessed by the TIMER command, and this timer is incremented each 56 ms; thus, looping until the timer has passed at least one increment ensures that the output lasts at least 56 ms).

```
DO
   RespX = INP(889)
   If PrevRespX − RespX = −8 THEN
      GOSUB Takeimage
   PrevRespX = RespX
LOOP

Takeimage:
OUT (888),1
   T = TIMER
   DO
   LOOP UNTIL TIMER > T + 0.056
OUT (888),0
   T = TIMER
   DO
   LOOP UNTIL TIMER > T + 1
RETURN
```

The program first loops until it detects a change in response input of −8. When this difference occurs, the program activates a subroutine that sends an output to Data Bit 1 (Pin 2) for at least 56 ms, which is sufficient to operate the shutter on the QuickCam®. To prevent multiple images from being taken if the rat were to bounce the omnidirectional pole, the program rests for 1 s following capture of each image, as illustrated in the second DO-LOOP in the Takeimage subroutine.